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CHAPTER THREE:
AGGREGATE PROPERTIES

The origin, distribution, and aggregate types found within Indiana were discussed in Chapter Two. The intent of this chapter is to familiarize the personnel responsible for aggregate testing with:

1) Related physical properties;

2) Chemical properties; and

3) General field characteristics of these aggregates.

Recognition of these properties and characteristics will assist the technician in evaluating the different aggregates used in highway construction.

Aggregate particles have certain physical and chemical properties which make the aggregate acceptable or unacceptable for specific uses and conditions. The following are of concern to INDOT.

PHYSICAL PROPERTIES

The physical properties of aggregates are those that refer to the physical structure of the particles that make up the aggregate.

ABSORPTION,POROSITY, AND PERMEABILITY

The internal pore characteristics are very important properties of aggregates. The size, the number, and the continuity of the pores through an aggregate particle can affect the strength of the aggregate, abrasion resistance, surface texture, specific gravity, bonding capabilities, and resistance to freezing and thawing action. Absorption relates to the particle's ability to take in a liquid. Porosity is a ratio of the volume of the pores to the total volume of the particle. Permeability refers to the particle's ability to allow liquids to pass through. If the rock pores are not connected, a rock can have high porosity and low permeability.

SURFACE TEXTURE

Surface texture is the pattern and the relative roughness or smoothness of the aggregate particle. Surface texture plays a big role in developing the bond between an aggregate particle and a cementing material. A rough surface texture gives the cementing material something to grip, producing a stronger bond, and thus creating a stronger hot mix asphalt or portland cement concrete. Surface texture also affects the workability of hot mix asphalt, the asphalt requirements of hot mix asphalt, and the water requirements of portland cement concrete.

Be conscious that some aggregates may initially have good surface texture, but may polish smooth later under traffic. These aggregates are unacceptable for final wearing surfaces. Limestone usually falls into this category. Dolomite does not, in general, when the magnesium content exceeds a minimum quantity of the material.

STRENGTH AND ELASTICITY

Strength is a measure of the ability of an aggregate particle to stand up to pulling or crushing forces. Elasticity measures the “stretch” in a particle.

High strength and elasticity are desirable in aggregate base and surface courses. These qualities minimize the rate of disintegration and maximize the stability of the compacted material. The best results for portland cement concrete may be obtained by compromising between high and low strength, and elasticity. This permits volumetric changes to take place more uniformly throughout the concrete.

DENSITY AND SPECIFIC GRAVITY

Density is the mass per unit of volume of a substance. Specific gravity is the ratio of the density of the substance to the density of water.

The following chart illustrates these relationships for some common substances.

Typical Values		
Substance	**Specific Gravity**	**Density (lb/ft^3)**
Water	1.0	62.4 lb/ft^3
Limestone	2.7	165 to 170 lb/ft^3
Lead	11.0	680 to 690 lb/ft^3

The density and the specific gravity of an aggregate particle is dependent upon the density and specific gravity of the minerals making up the particle and upon the porosity of the particle. These may be defined as follows:

1) All of the pore space (bulk density or specific gravity);

2) Some of the pore space (effective density or specific gravity); or

3) None of the pore space (apparent density or specific gravity).

Determining the porosity of aggregate is often necessary, but it is difficult to directly measure the volume of pore space. Correlations can be made between porosity and the bulk, apparent and effective specific gravities of the aggregate.

As an example, specific gravity information about a particular aggregate will help in determining the amount of asphalt needed in the hot mix asphalt. If an aggregate is highly absorptive, the aggregate will continue to absorb asphalt, after initial mixing at the plant, until the mix cools down completely. This process will leave less asphalt for bonding purposes; therefore, a more porous aggregate requires more asphalt than a less porous aggregate. The porosity of the aggregate can be taken into consideration in determining the amount of asphalt required by applying the three types of specific gravity measurements.

In the example in Figure 3-1 the bulk specific gravity includes all the pores, the apparent specific gravity does not include any of the pores that would fill with water during a soaking, and the effective specific gravity excludes only those pores that would absorb asphalt. Correlation charts and tables provide guidance to asphalt quantities or acceptability of the aggregate.

AGGREGATE VOIDS

There are aggregate particle voids, and there are voids between aggregate particles. As solid as aggregate may be to the naked eye, most aggregate particles have voids--natural pores that are filled with air or water. These voids or pores influence the specific gravity and absorption of the aggregate materials.

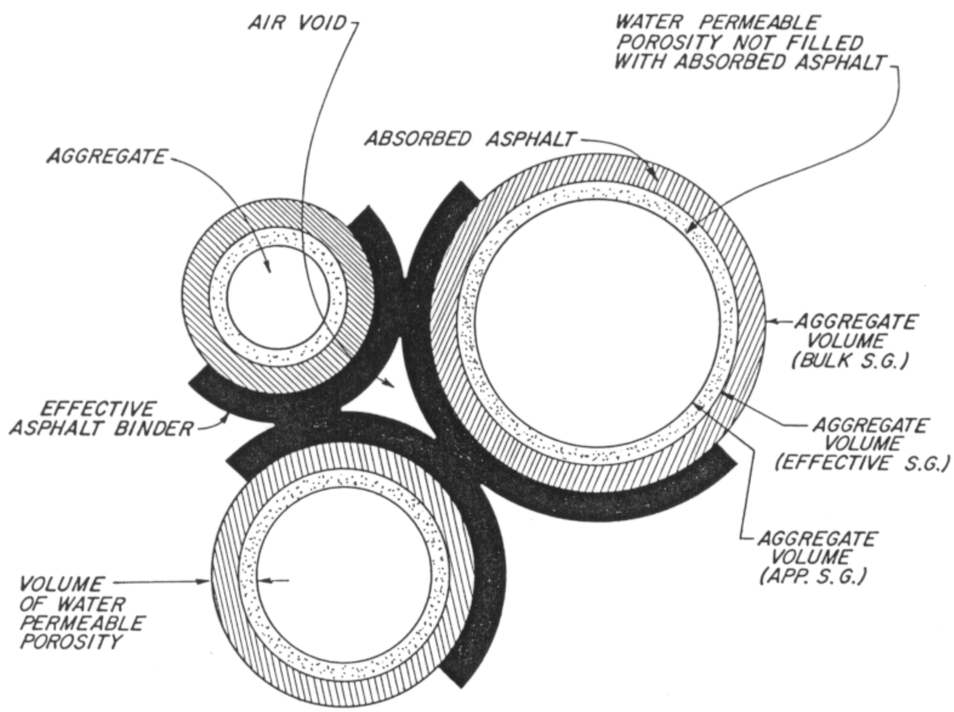

Figure 3-1. Aggregate specific gravities.

The voids within an aggregate particle should not be confused with the void system which makes up the space between particles in an aggregate mass. The voids between the particles influence the design of hot mix asphalt or portland cement concrete.

HARDNESS

The hardness of the minerals that make up the aggregate particles and the firmness with which the individual grains are cemented or interlocked control the resistance of the aggregate to abrasion and degradation. Soft aggregate particles are composed of minerals with a low degree of hardness. Weak particles have poor cementation. Neither type are acceptable. Geologists and engineers frequently use the Mohs Hardness Scale for determination of mineral hardness (Figure 3-2). Although there is no recognizable INDOT specification or requirement which pertains to Mohs Hardness Scale, the interpretation, concept, and use of this scale is useful for the field identification of potentially inferior aggregates.

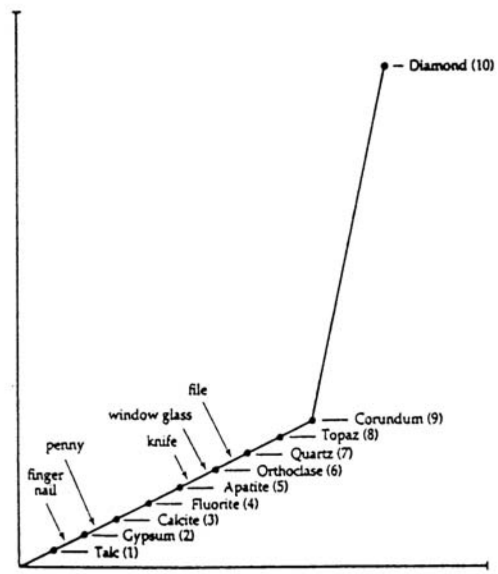

Figure 3-2. Relative hardness of minerals in Mohs scale (numbers in parentheses).

PARTICLE SHAPE

The shape of the aggregate particles affect such things as:

1) The asphalt demands of hot mix asphalt; and

2) The workability and the strength of both portland cement concrete and asphalt pavements.

The best aggregates to use for strength are crushed stone or crushed gravel. Crushed aggregate have irregular, angular particles that tend to interlock when compacted or consolidated.

The crushed stone or crushed gravel aggregate make the asphalt or concrete mix somewhat difficult to place. To improve the workability, many mixes contain both angular and round particles. The coarse aggregate particles are usually crushed stone or crushed gravel, and the fine aggregate particles are usually natural sand. The Standard Specifications detail the requirements for crushed materials for various uses.

COATINGS

Coating is a layer of substance covering a part or all of the surface of an aggregate particle. The coating may be of natural origin, such as mineral deposits formed in sand and gravel by ground water, or it may be artificial, such as dust formed by crushing and handling.

Generally when the aggregates are used in hot mix asphalt or portland cement concrete mixes, the aggregates must be washed to remove the coating (contaminant) left on the particles. The coating may prevent a good bond from forming between the aggregate surfaces and the cementing agent. The coating could even increase the quantity of bonding agent needed in the mixture. If the quantity of the coating varies from batch to batch, undesirable fluctuations in the consistency of the mix may result. Deposits containing aggregates which display a history of coating problems shall be subjected to decantation.

UNDESIRABLE PHYSICAL COMPONENTS

These items will be discussed in more detail in Chapters 4 and 9, but at this juncture undesirable physical components of aggregates will be introduced.

Particles of this type include but are not limited to the following:

1) Non-durable soft or structurally weak particles;
2) Clay lumps or clay balls;
3) Flat or elongated particles;
4) Organic matter contaminants; and
5) Lightweight chert.

CHEMICAL PROPERTIES

The chemical properties of aggregates have to do with the molecular structure of the minerals in the aggregate particles.

COMPOSITION

The chemical composition of aggregate is significant in determining the difference between limestone and dolomite. Limestone is a rock consisting mainly or wholly of calcium carbonate. Limestone has a tendency to polish smooth under traffic. Therefore, limestone is limited to use in low traffic-volume HMA surface courses. Dolostone under traffic maintains a higher-friction, skid-resistant surface and is used on higher traffic volume locations. Dolostone is a carbonate rock which consists largely of calcium magnesium carbonate. The word "dolomite" is the mineral calcium magnesium carbonate Ca Mg $(Co_3)_2$. INDOT uses an elemental magnesium (Mg) content test to determine if a rock source is dolomitic. An elemental magnesium content of 10.3 percent or above is required for dolomite aggregates.

Some aggregates have minerals that are subject to oxidation, hydration, and carbonation. These properties are not particularly harmful, except when the aggregates are used in portland cement concrete. As might be expected, iron sulfides, ferric and ferrous oxides, free lime, and free magnesia in industrial products and wastes are some of the common substances. Any of these substances can cause distress in the portland cement concrete and give it an unsightly appearance.

REACTIONS WITH ASPHALT AND CEMENT

There are several types of substances found in mineral aggregates which can have a negative effect on the cementing and overall performance qualities of asphalt and cement. Most are rarely significant but various organic substances can retard hardening, reduce strength development or cause excessive air entrainment in portland cement concrete. These organic substances include but are not limited to: mica, iron oxide, light-weight chert, shale, coal, and lignite.

SURFACE CHARGE

Aggregate particle surfaces possess either positive or negative electrical charges. Limestone and dolostone generally have a high affection for liquid asphalt.

GENERAL CHARACTERISTICS

Aggregates have three primary uses in highway construction:

1) As compacted aggregates in bases, subbases and shoulders;

2) As ingredients in hot mix asphalt; and

3) As ingredients in portland cement concrete.

Aggregates can also be used as special backfill material, riprap, mineral filler, and other less significant uses. The general requirements will be covered later in this manual.

COMPACTED AGGREGATES

Compacted aggregates without the addition of a cementing material can be used as a base or subbase for hot mix asphalt and portland cement concrete pavements. Portland cement concrete pavements are rigid pavements. For these types of pavements, the purpose of the base may be to improve drainage, to prevent pumping, or to cover a material that is highly susceptible to frost. Consequently, gradation and soundness are the primary considerations in selecting or evaluating aggregates for bases under rigid pavements.

The load-carrying capacity is a primary factor in the selection of aggregates for hot mix asphalt pavements. A hot mix asphalt pavement, by itself, cannot carry the load; help from the underlying base courses is required. In addition to gradation requirements, the aggregates must also possess the strength to carry and transmit the applied loads.

Aggregates are sometimes used to make up the entire pavement structure. In this type of pavement, aggregates are placed on the natural soil to serve as a base course and surface course. Again, the primary requirements deal with gradation.

In many instances, compacted aggregates are also used to construct roadway shoulders and berms. Here, gradation and stability are very important.

AGGREGATE FOR HOT MIX ASPHALT

INDOT uses hot mix asphalt in a number of different ways. In all cases the aggregates used should meet five requirements:

1) Strong, tough and durable;

2) The ability to be crushed into bulky particles, without many flaky particles, slivers or pieces that are thin and elongated;

3) Low porosity

4) Low permeability; and

5) Correct particle size and gradation for the type of pavement.

AGGREGATES FOR PORTLAND CEMENT CONCRETE

There are many uses of portland cement concrete in highway construction. Some of the major uses of aggregates are: in rigid-pavement slabs, bridges, concrete barriers, sidewalks, curbs, slopewalls, and other structures.

Aggregates in portland cement concrete should always be physically and chemically stable. Other factors to be considered include:

1) The size, distribution, and interconnection of voids within individual particles;

2) The surface character and texture of the particles;

3) The gradation of the coarse and fine aggregates;

4) The mineral composition of the particles;

5) The particle shape;

6) Soundness abrasion resistance; and

7) Water absorption.

OTHER AGGREGATES

There are other uses for aggregates in highway construction. The requirements will be somewhat different from the ones already discussed; however in most cases, gradation as a controlling factor will be common to all applications.